SIM Astrometric Grid (2)

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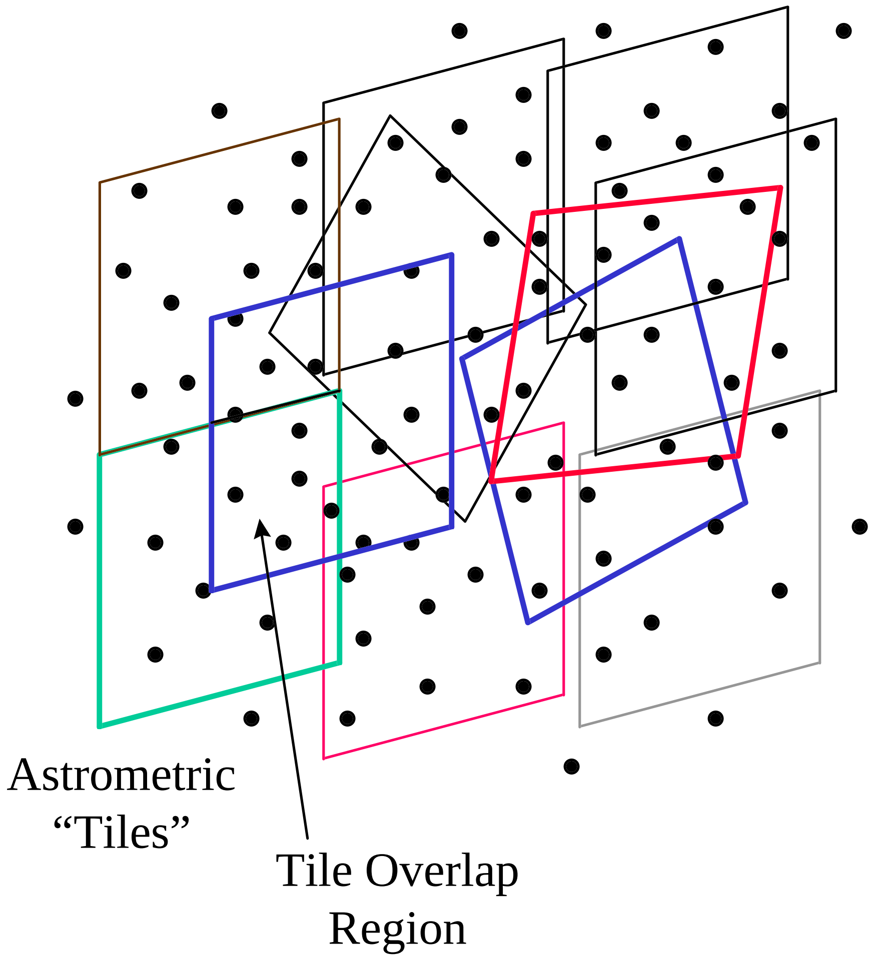
Topics

- SIM Grid Astrometric Model
- Grid Size
- Grid Observation Scenario(s)
- Grid Simulation
- Solution Techniques
- Astrometric FOV Results
- Grid Lock-up Results
- Constant Term Results
- Conclusions and Future Plans

SIM Astrometric Grid

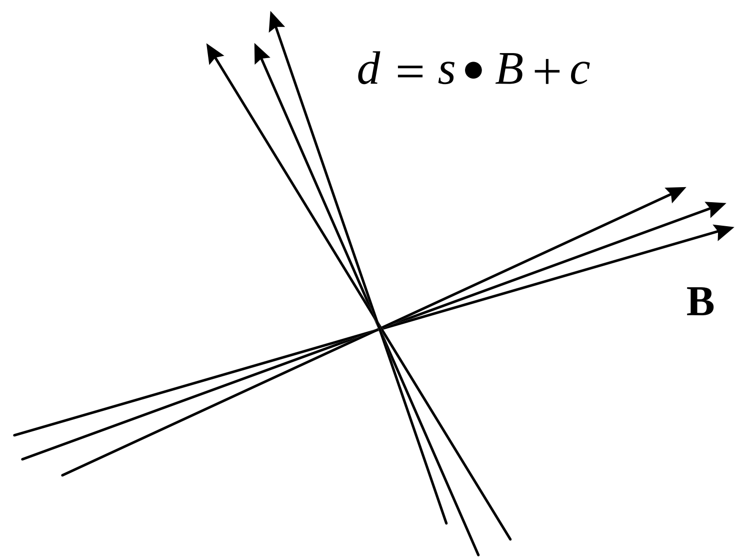
- The SIM Astrometric Grid Serves as Both the Mechanism Supporting Wide-Angle Astrometry, and the Global Astrometric Calibration of the Instrument.
- Grid is Composed of ~3000 Objects Distributed Quasi-Uniformly Over the Celestial Sphere, Including O(100) QSO's to Establish an (Quasi) Inertial Reference/Extragalactic Tie.
- Grid Observations Lead To an Estimate of Grid Object Astrometric Parameters (Grid Reduction).

SIM Astrometric Measurements



- 4π Sky Sampled By Discrete Pointings That We Call “Tiles”
- Object Delays Are Measured *Serially*, *Common* Baseline Orientation Ties Delay Measurements Together
- Objects in Tile Overlap Region Tie the Tiles Together
- Quasi-Orthogonal Baseline Projections To Achieve Isotropic Position Errors

$$d = s \bullet B + c$$



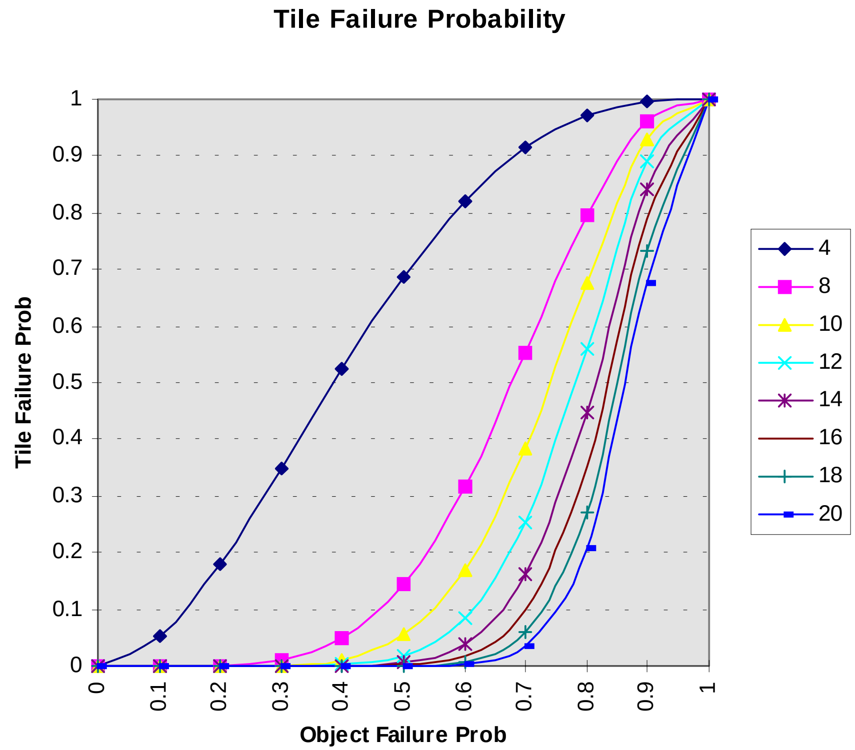
SIM Astrometric Measurement Model

- I Use the "Colavita" Model For SIM Astrometry:
  - Only One Baseline Used For Grid/Science Observations (Reduced Systematic Errors)
  - Guide Interferometers Used Only To Measure *Changes* in the Baseline Attitude -- Absolute Attitude Estimated in Grid Reduction
  - Measurements From Tiles Can Be "Regularized" (Modeled To Have Come From A Single Baseline Attitude) Using Guide Interferometer Rate Information and Relative Metrology
  - Absolute Scale (Baseline Length) Estimated in Grid Reduction
- Alternative: Relative "Angles" Measured Between Interferometer Baselines (Loiseau and Malbet Model -- A&AS **116** 373-380)
  - Requires Accurate Relative Calibration Between Interferometer Baselines

SIM Astrometric Grid Size

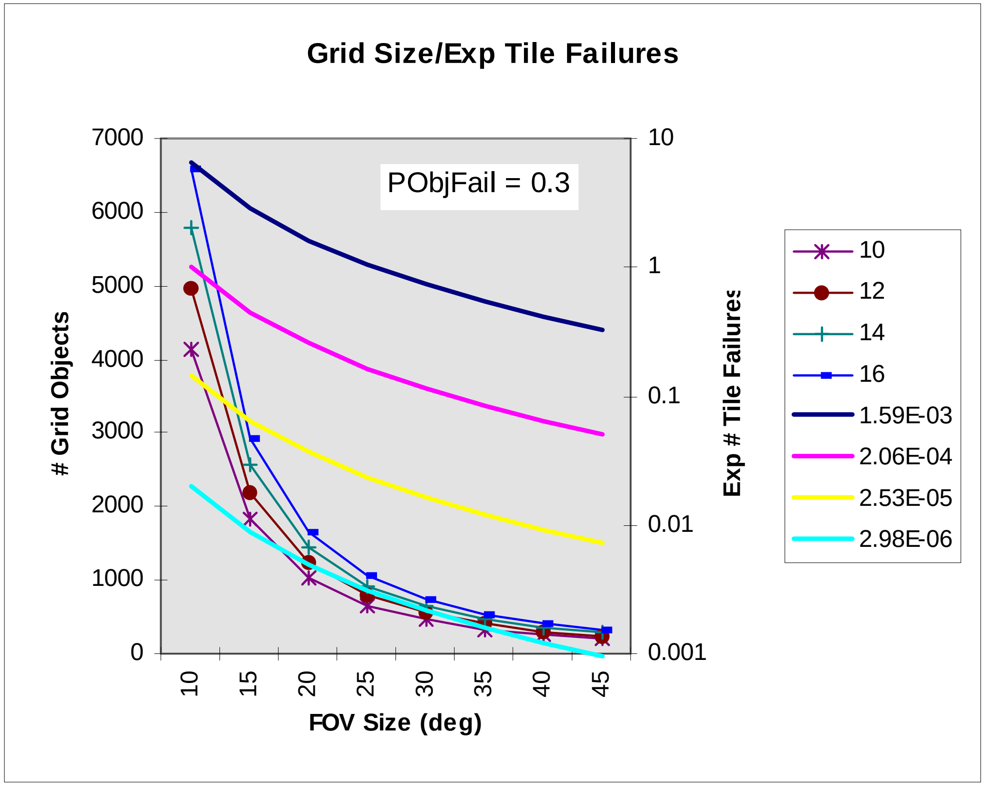
- Size of Grid (# Objects) Dictated by:
  - Astrometric FOV
  - Minimum 3--4 Objects/Tile
  - $P_{ObjFail}$
  - *Acceptable* $P_{TileFail}$
- Tile Failure Probability Given by Object Failure Probability and Binomial Statistics

$$P_{TileFail} = 1 - \sum_{i=M}^{N} \binom{N}{i} P_{objFail}^{N-i} (1 - P_{objFail})^{i}$$



SIM Astrometric Grid Size (2)

- 10deg Field: 4000 -- 7000 Objects
- 15deg Field: 2000 -- 3000 Objects
- Trade Among:
  - Exp. Number of Tile Failures
  - Grid Observing Time
- …Driven by $P_{ObjFail}$

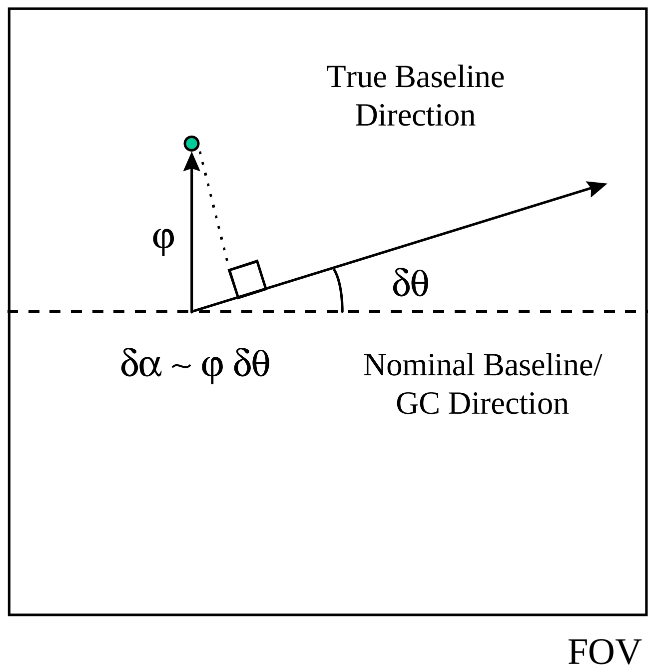


Grid Observations/Scenario

- Grid Observations ***Can*** Be Made by a Specific Scheme. Or ***Not***.
- Possibility of "Minor" Closures (*e.g*. GC, Partial Peel) To Solve For "Short-Term" Variations in Instrument Parameters.
- Current Strawman: Orange Peel Scan Law.
- Looked-at "Hipparcos-Like" Great Circle Scan Law, But "Hipparcos-Like" Reductions Are Unsuitable For SIM.

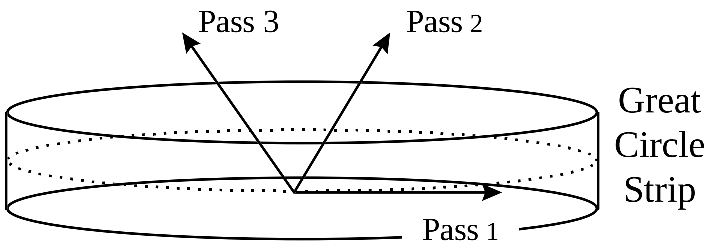
(Non)Applicability of Great Circle Reductions

- Direct Applicability of Great Circle Reductions is Limited:
  - Abscissa Error $\delta\alpha \sim \varphi\ \delta\theta$
  - For $\varphi \sim 5$ deg, $\delta\theta \sim 1$ mas, $\delta\alpha \sim 100\ \mu$as
- Possibilities:
  - Decrease φ (*Increases* Grid Size)
  - Multiple Passes Over a Peel Fraction that Approximates a "Fat" Great Circle -- 2d Solution



“Fat” Great Circle Concept

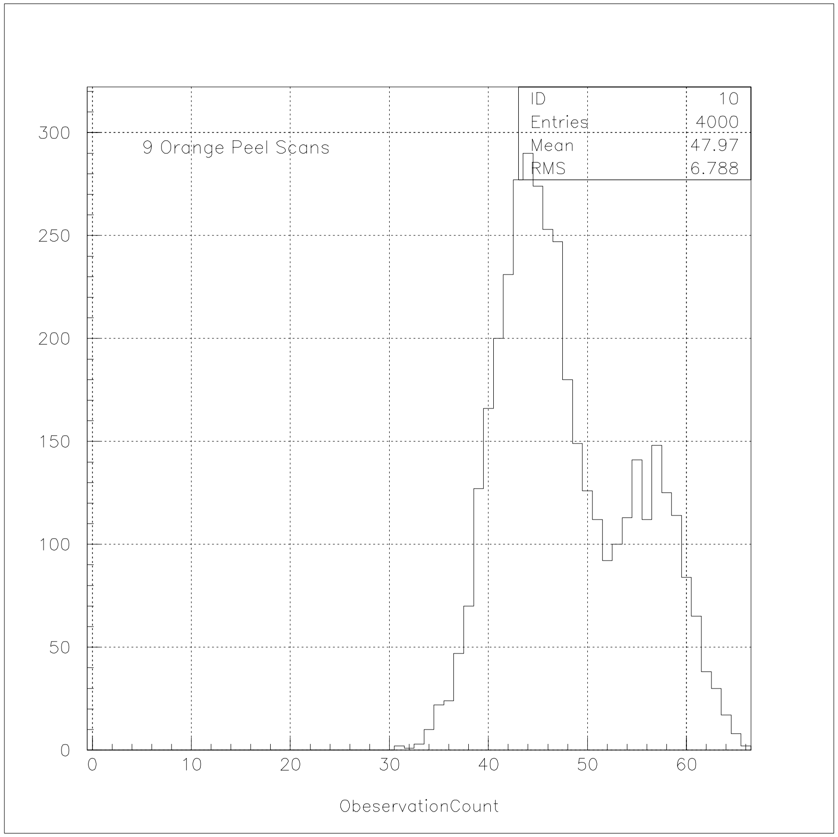
- Similar in Concept To Hipparcos GC Reductions
  - Uses 2π “Minor” Closure Condition on GC Abscissa
  - Estimates “Average” Positions and Instrument Parameters



- But
  - Additional Passes With Baseline Oriented to Measure Mixed Abscissa-Ordinate Position
  - Estimates (Average) Object Abscissa *and* Ordinate Positions
- 20 Hrs To Complete (SIM Turbo)

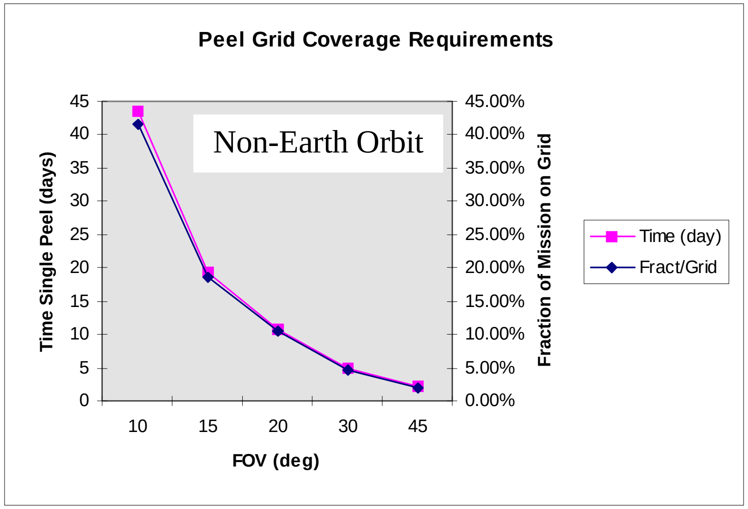
“Orange Peel” Scan Law

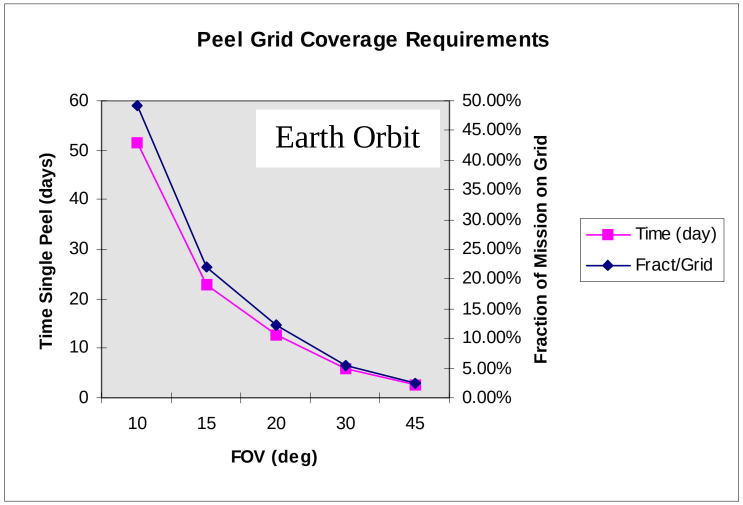
- Systematic “Brick-Work” Coverage of Available Sky Using the Anti-Sun Direction As Symmetry Axis
- Better Observation Uniformity Than Hipparcos Scan Law



Orange Peel Operational Requirements

- OP Grid Coverage Takes a Reasonable Fraction of Mission Time Either In or Out of Earth Orbit.
- “Aggressive” Assumption Set (“SIM Turbo”) For Spacecraft and Instrument Retargeting Performance
  - Reaction Wheel Size
  - Delay Line Slew Rate





Astrometric Grid Simulations

- Status: Rapid Prototype Implementation of
  - Random Grid Generation and Initial Estimate
  - Scan Law Definition
  - (“Cheese-ball”) Measurement Generation
    - Equal-Sigma Gaussian Errors on All Objects
  - Grid Reduction
    - Fitting Classical Astrometric Parameters (Position, Proper Motion, and Parallax) to Measurement Set
  - Empirical (Monte Carlo) Parameter Residual Analysis
- Prototype 2d Code and Evolved it into the 3d Code
- Object Oriented Implementations in C++ -- the *best* way to get other people to do your work for you...

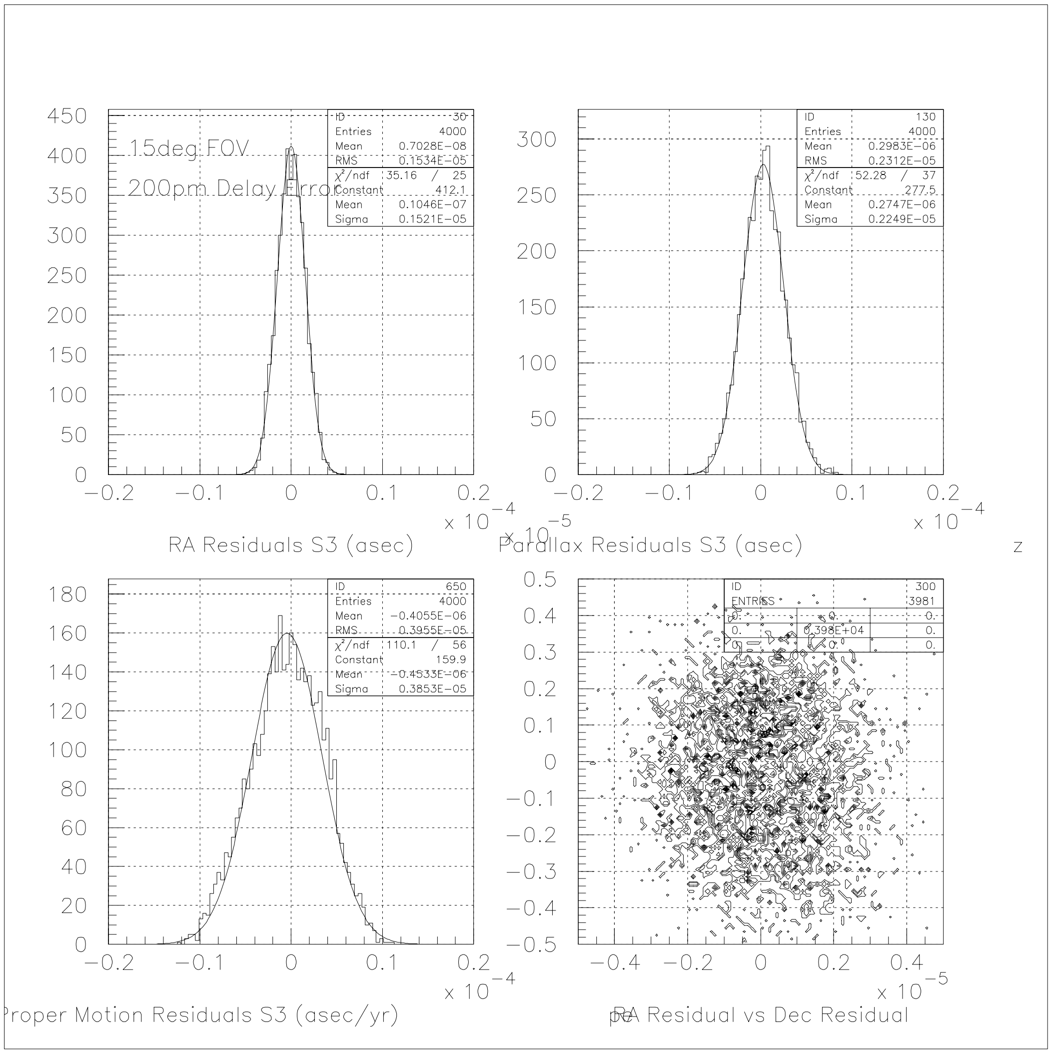
Grid Solution Technique/Implementation

- “Difference” Observation Equation Formed
- (Iterative) Linear Least Squares Solution for *Corrections* to Input Instrument, Catalog Parameters
- System is *Very Large* (O(*few**10^5) by O(*few**10^4)) and *Sparse* (O(10^{-4}))
- Solution by Conjugate Gradient on the Normal Equations (CGNE -- Itself Iterative)
- Computational Bottleneck Normal Product Formed *Concurrently* (Recently Improved)
- Numerical Roundoff Below the nas Level

Grid Residual Error Analysis

RA Position

Parallax

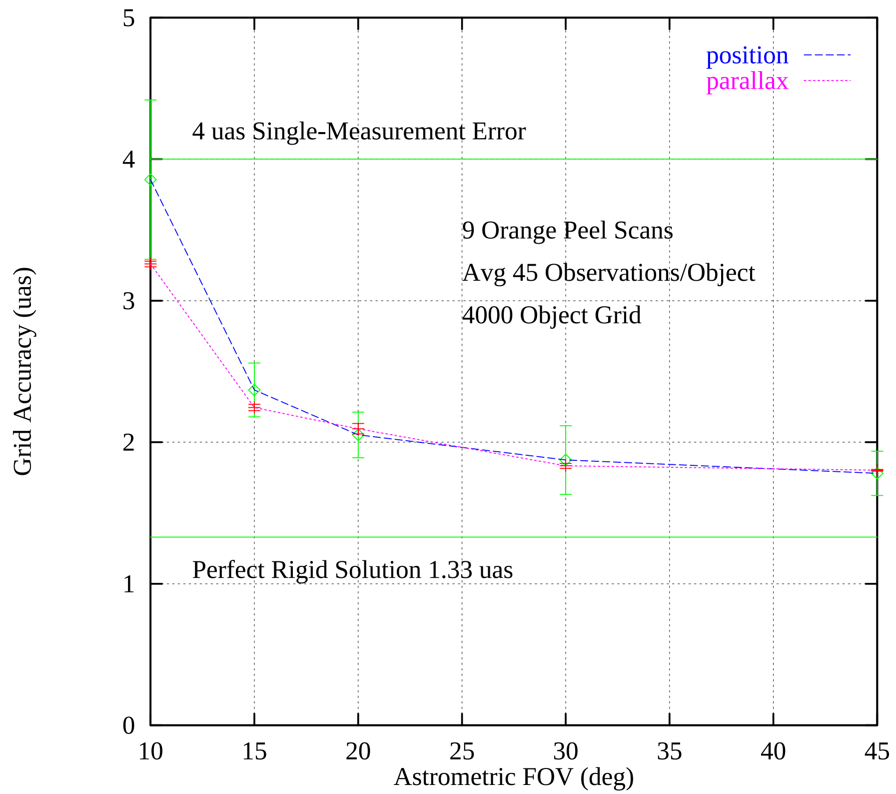


Dec Proper Motion

RA/Dec Error Scatter

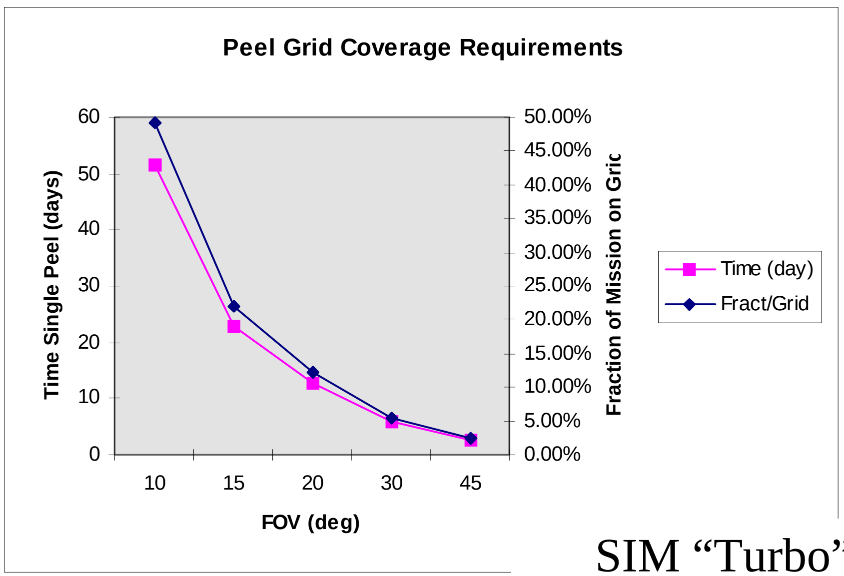
SIM Astrometric FOV

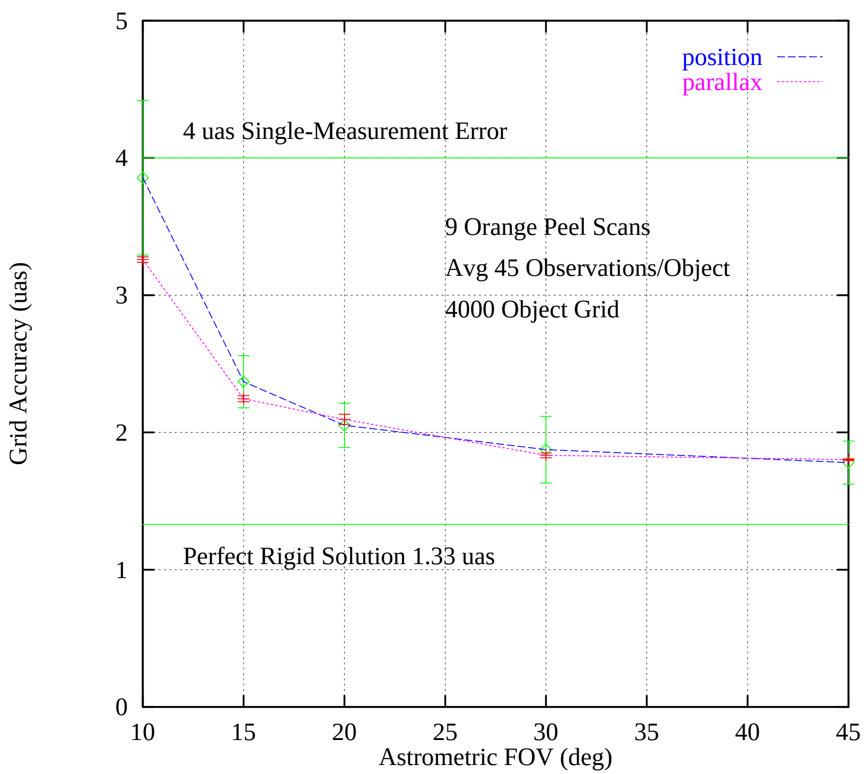
- Survey of Grid "Rigidity" vs. Astrometric FOV
  - 4 μas Single-Measurement Precision (Gaussian Sigma)
  - Fixed Size (4000) Grid
  - 43deg Sun Exclusion Angle
  - 9 Orange Peel Scans (2 yrs)
  - Position, Proper Motion, and Parallax in the Solution
- Recommendation to Project to Increase Strawman FOV to 15deg



The Case For a 15deg FOV

- With a 15deg FOV you win two ways:
  - Better Grid Performance
  - Faster Sky Coverage (More Time For Science)

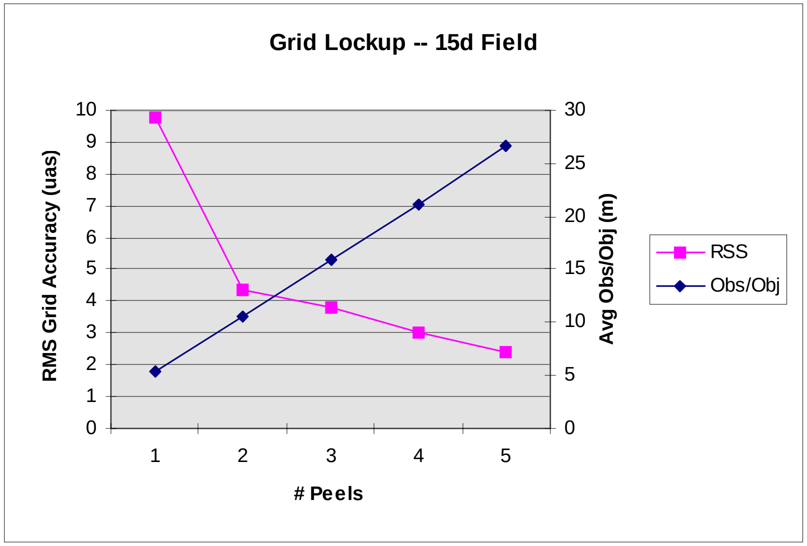




SIM "Turbo" in Earth Orbit
100 s Min Obs (Not Phot Limited)

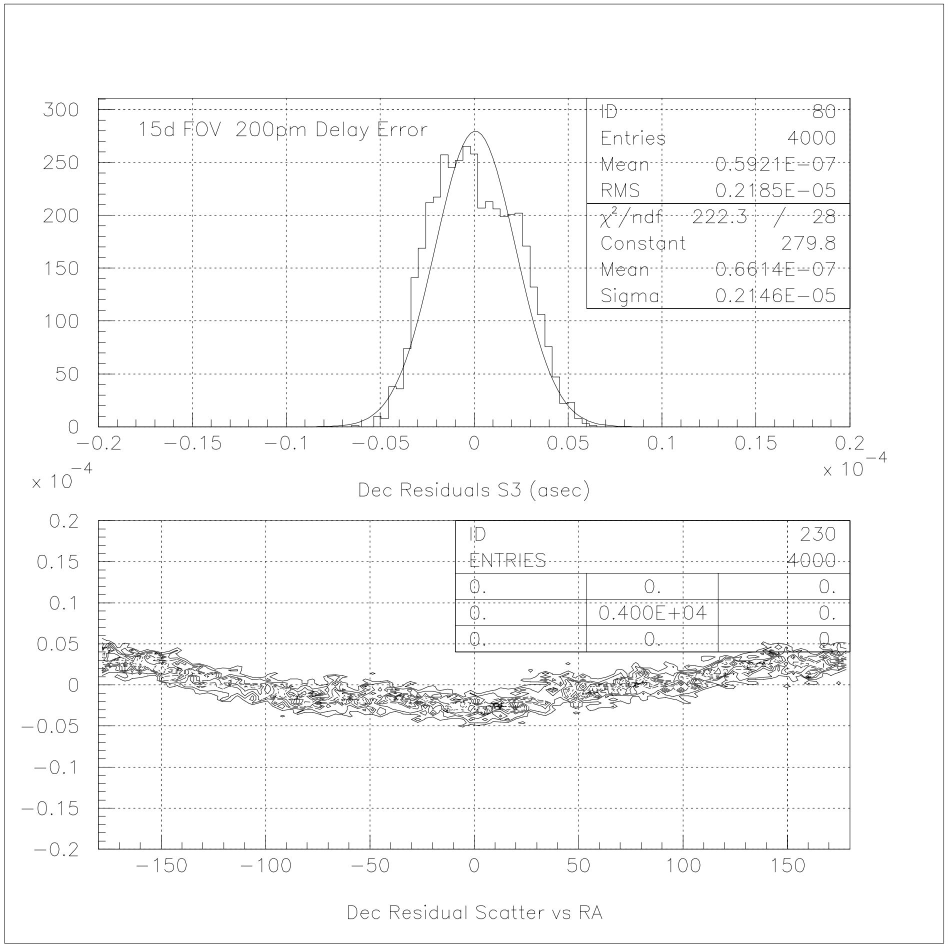
Grid “Lock-Up” Results

- Grid “Lock-up” Defined By The Number of Observations/Object (M) Required for Grid Accuracy Equal to Single-Measurement Accuracy.
- 15d Field -- Lock-up at M~12 (45d M~8)
- Recall POINTS Lockup at M~8.4 (4.2)



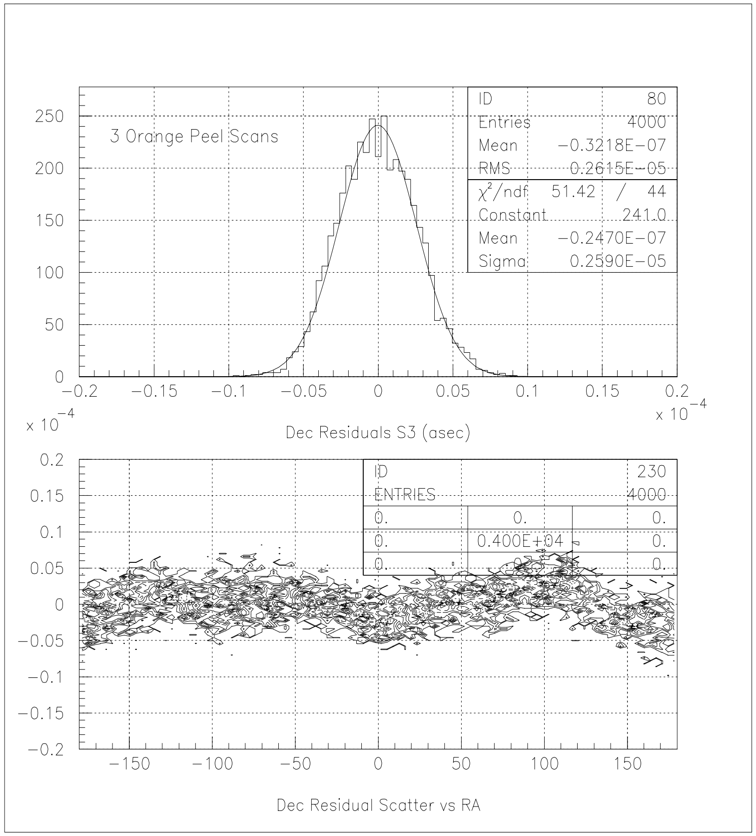
SIM Grid Errors

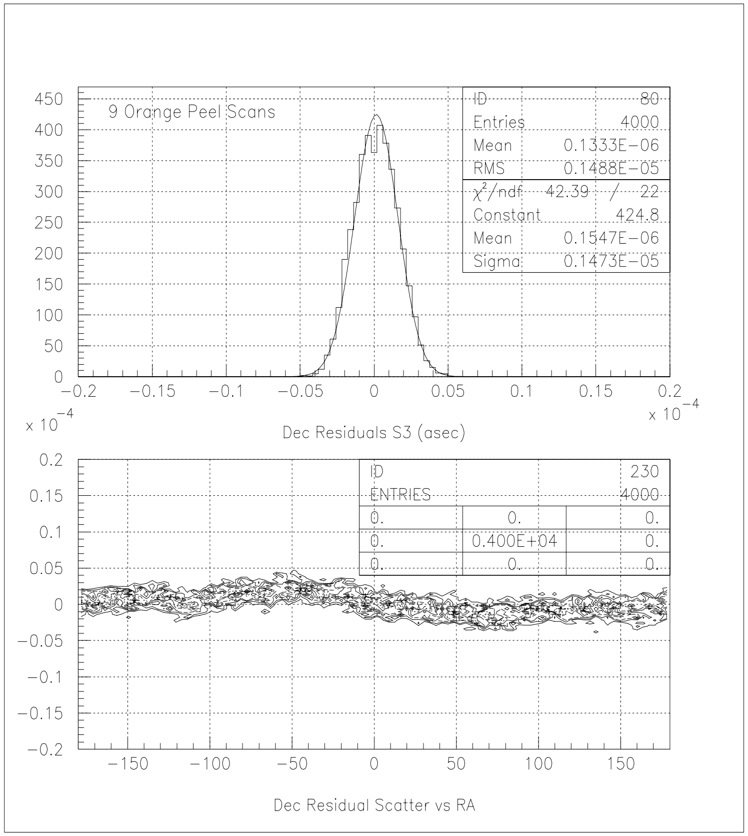
- 4π Grid Errors Contain Both Correlated (Zonal) and Uncorrelated (Local) Components.
- Different Science Programs Will Have Different Sensitivities to Grid Errors.



Non-Rigidity in the Grid Solutions

- Non-Rigidity in the Grid Solutions Manifested as “Zonal” Errors





Astrophysical Issues For SIM Astrometric Grid

- Grid Quality (and Measurement Quantity) Depends on Grid Objects Being Astrometrically "Simple" (Position, Proper Motion, Parallax)
  - Proliferation of Astrometric Parameters Leads to Loss of Grid Solution Rigidity (Bad)
- Astrometric Jitter Sources
  - Undetected Binarity
  - *Planetary Companions*
  - StarSpots
  - Gravitational Microlensing
  - Energetic Outflows (QSOs)

MS Spec Type	Astrometric Signature (μas)	Max RV (m/s)	Orbit Period (yrs)
B0V	0.5	3.2	2.7
B5V	1.5	5.2	4.4
A0V	3.1	7.4	6.2
A5V	4.8	9.2	7.7
Sun	9.9	13.3	12

Effects of A Jupiter Mass/Orbit Companion to Some Early MS Stars @ 1kpc

Grid Constituents

- Likely Grid Constituents Unclear at Present
  - QSOs For Extragalactic Tie
    - Signs of ~25μas Astrometric Jitter in Radio (VLBI)
  - Early-Type MS Stars @ 1kpc Are My Favorite
    - Distance Mitigates Jitter From Planetary Companions
  - G-type Stars Well Studied in Radial Velocity Programs
    - Radial Velocity Programs Don’t Probe Right Phase Space
  - Bright Giants and Supergiants
    - Subject To Spotting, Confined To Disk (Pop 1)
- Significant Ground-Based Program To Identify Candidates (PTI, Keck Interferometer, Spectroscopy, Astrometric Imaging)

Systematic Errors

- Just Starting to Play With Unmodeled Systematic Errors
  - Quick Experiment With A Quadratic (Symmetric!) Field-Dependent Push Equal To 1-Sigma Phase Noise
  - Few Measurements (6): Grid Errors Roughly Double (1.8)
  - Many Measurements (45): Grid Errors Increase As RSS of Systematic and Phase Noise (1.2)
  - Conclusion: Multiple Measurements Tend to "Randomize" the Systematic Contribution

One vs. Many Cs

- Open Issue of the Time Variability of the Interferometer "Constant Term"
- Ongoing Study of Grid Performance Degradation for One Global C vs One C Per Tile
- Preliminary Conclusion: No Big Deal

Grid Degradation Factor With Many C (Preliminary)

FOV (deg)	Position	Parallax	Proper Motion	Parameter Increase %
10	1.24	1.21	-	35%
15	1.05	1.05	1.25	26%
45*	1.2	1.12	1.04	67%

* 300 Object Test Case

Conclusions

- Grid Size (Mission Fraction) Strongly Dependent on FOV, P_{fail}
- Grid Rigidity (Accuracy per Observation) Strongly Dependent on FOV
- Grid Errors Come in Local and Zonal Flavors, Impact Individual Science Programs Differently
- Constituency of the Grid is Uncertain at Present

Plans/To Do List

- Mission/Instrument Trade Studies
  - Sky Coverage Trades (an Eye Towards “Minor” Closures)
  - Metrology Drop-Out Rate (Probability) Implications
  - Instrument Calibrations (*e.g.* Estimating Systematic Errors)
  - (Non-Local) Implications of Tile Faults
- High-Fidelity Instrument Simulator (Laskin/Milman)
  - Effort To Merge (Mostly Pre-Existing) Hi-Fi Structures, Optics, and Detector Models Into an Integrated Instrument Model
- Astrophysics Front-Ends (Binarity, Planets, GR Lensing) Appropriate to Candidate Grid Objects
- Fit Performance With Ancillary Instrument Parameters
- Identification of “Troublesome” Objects in the Grid